CALIFORNIA DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-130

August 31, 1982

1. Name of fault.

Goose Lake and related faults, Humboldt County.*

2. Location of fault.

Hydesville 7.5-minute quadrangle.

3. References.

Coppersmith, K. J., October 1980, Appendix B, Summary of exploration locality investigations, in Woodward-Clyde Consultants, Evaluation of the potential for resolving the geologic and seismic issues at the Humboldt Bay Power Plant Unit Number 3: Unpublished consulting report prepared for Pacific Gas and Electric Company, 107 p.

Earth Science Associates, 1976, Humboldt Bay Power Plant site geology investigation: Unpublished consulting report for the Pacific Gas and Electric Company, 101 p., 36 figures, 19 plates, 8 appendices (variously paginated).

Evenson, R. E., 1959, Geology and ground-water features of the Eureka area, Humboldt County, California: U.S. Geological Survey Water-supply Paper 1470, 80 p., 2 plates, plate 1 (1:62,500).

Hart, E. W., 1980, Fault-rupture hazard zones in California: California Division of Mines and Geology Special Publication 42, 25 p.

Ogle, B. A., 1953, Geology of the Eel River area, Humboldt County, California: California Division of Mines Bulletin 164, 128 p., 6 plates, plate 1 (1:62,500).

Strand, R. G., 1962, Geologic map of California, Redding sheet: California Division of Mines and Geology (1:250,000).

Turcotte, T., Hutchings, L., Simon, R., and Somerville, P., October 1980, Appendix D, Summary of seismicity investigations, in Woodward-Clyde Consultants, Evaluation of the potential for resolving the geologic

* The Little Salmon and Yager faults are not evaluated in this FER although they are shown on the accompanying maps. See FER-142 for the evaluation of these two faults.

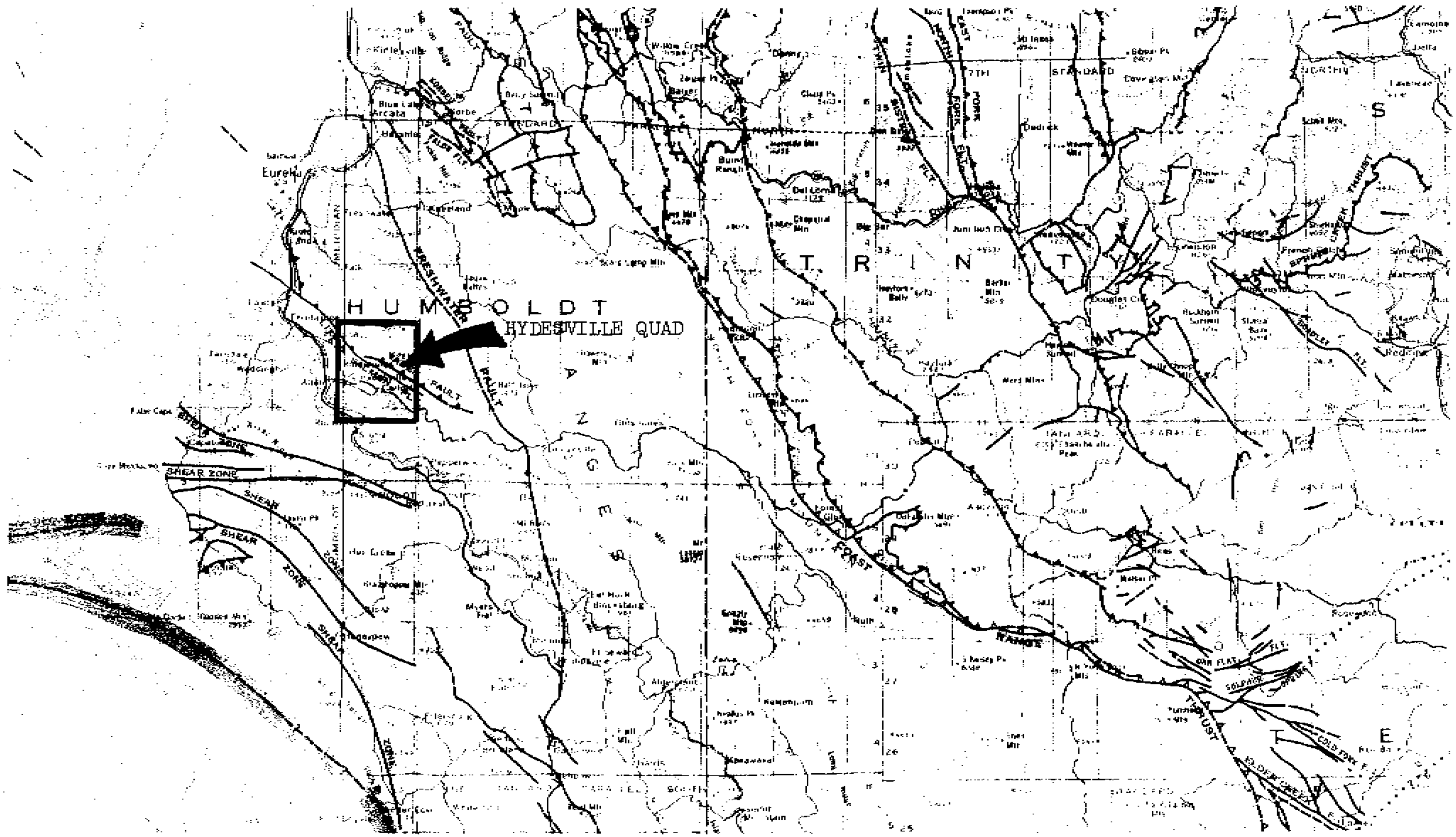

Figure 1. Location of the Hydesville 7.5-minute quadrangle. Base map from Jennings (1975) Fault Map of California.

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and seismic issues at the Humboldt Bay Power Plant Unit Number 3: Unpublished consulting report prepared for Pacific Gas and Electric Company, 145 p.

Woodward-Clyde Consultants, October 1980, Evaluation of the potential for resolving the geologic and seismic issues at the Humboldt Bay Power Plant Unit Number 3: Unpublished consulting report for Pacific Gas and Electric Company, Summary Report, 74 p., Appendices, (variously paginated), 606 p.

U.S. Department of Agriculture, 1954, Black and white aerial photos, CVL series, flight 7N, numbers 76 to 82, 93 to 96, 165 to 169, and flight 13N, numbers 126 to 130, scale 1:20,000.

U.S. Geological Survey, 1947, Black and white aerial photos, GS-EG series, flight 3, numbers 148 to 151, 189 to 199, 221 to 222, and 234 to 238, scale 1:37,400.

U.S. Geological Survey, 1972, Black and white aerial photos, GS-VCZ series, flight 3, numbers 116 to 120, 147 to 151, and 160 to 164, scale 1:50,000.

4. Summary of available information.

Woodward-Clyde Consultants (1980), while conducting a study of the tectonics of the region around the Humboldt Bay nuclear power plant, discovered and investigated the Goose Lake fault near Hydesville. Earlier workers (Ogle, 1953; Evenson, 1959; Strand, 1962; and Earth Science Associates, 1976) had not detected either the Goose Lake or related recently active faults.

All of the data currently available on the Goose Lake fault is contained in the Woodward-Clyde (1980) report. Appendix B (by Coppersmith) contains a relatively detailed discussion of the data relating to the faulting observed in the area.

Coppersmith (1980) reported finding three major, well-defined lineaments near Hydesville that trend subparallel to the mapped trace of the Little Salmon fault (see Figure 2). He noted that the terraces of Yager Creek differ in number and elevation across these lineaments. The purpose of his study was to determine whether the lineaments were faults and, if so, to obtain information on the style, recency, and sense of faulting, recurrence interval, and rate of displacement. Stevens (personal communication, October, 1981) reported that Woodward-Clyde was denied access to the lineament having the greatest apparent offset (Fault A on Figure 2).

Based on the trench data and other geologic information, Coppersmith concluded that all three lineaments are coincident with faults, and that some of the terraces were formed synchronously with fault movement. He also stated (p. B-12) that these lineaments are not apparent west of the Yager Creek terraces or east of Yager Creek.

The Goose Lake fault was the most intensively studied of the three lineaments. Coppersmith describes the feature as a two-kilometer long linear ridge and line of scarps adjacent to the historically drained Goose Lake. Where trenched, the low ridge has a six to seven-meter high north face and a two-meter high south face, slightly modified by cattle. All the materials trenched were less than 700,000 years old. Two Carbon-14 dates (16,100$\pm$110 ybp; 8716$\pm$195 ybp) were obtained from the lake sediment on either side of the fault.

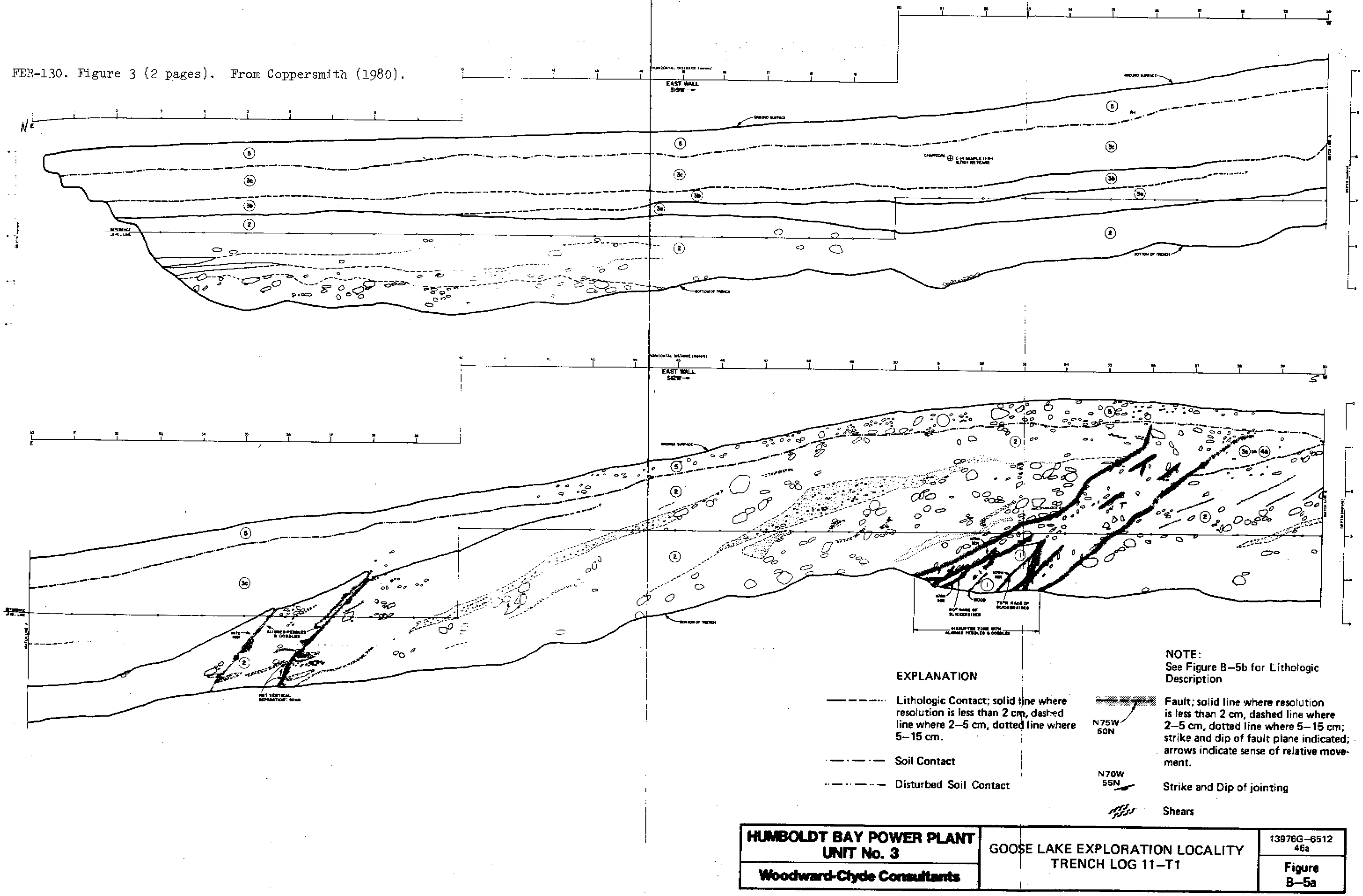
(Note that Coppersmith (1980, p. B-10 and B-11) contains two figures which show different locations for the west end of the Goose Lake fault and the trench. It is apparent that the fault is misplotted on p. B-10.)

Coppersmith (1980, p. B-14 to B-21) reported finding two distinct zones of northeast-dipping reverse faults (having strikes of N75°W to N85°W, and dips of 45° to 75° NE) which coincide with two one-meter high inflections of the ground surface along the linear ridge. Stevens (p.c.) feels that these two inflections are probably the result of cattle traversing the site and compacting and displacing the soil. Coppersmith reported that the fault surfaces were best preserved in the Carlotta Formation, where slickensides with rakes of 50°W to 75°W were observed. Because the materials exposed within the fault zone consist of coarse gravels, Coppersmith concluded that the majority of the deformation took place as intergranular rotation.

Coppersmith noted that the geologic units along the fault appear "progressively warped with age," suggesting repeated fault movement has occurred during the Quaternary. Based on the stratigraphic relationships he concluded there was evidence of at least three episodes of displacement exposed in the trenches. He reported that lake deposits younger than 16,000±110 years before present (ybp) are in fault contact with older Yager Creek alluvium (Figure 3 , station 70). He also cited additional young faults some of which displace the contact between young lake deposits and older alluvium, but he lacked evidence that would conclusively demonstrate, beyond any question, that Holocene fault movement had occurred. He did conclude that warping of the lake sediments (dated 8715±195 ybp) (and, possibly, displacement) has occurred.

Coppersmith also (p. B20-21) discussed both the rate of slip and the displacement per event. If the lake sediments on either side of the fault are correlative, then the net displacement is 4.0 to 8.5 meters; if they are not correlative, then the net could be considerably less. Using the assumption that the lake deposits are correlative (both in age and in original elevation), Coppersmith arrived at a net slip rate of 0.3 to 1.0 millimeters per year.

FER-130. Figure 3 (2 pages). From Coppersmith (1980).



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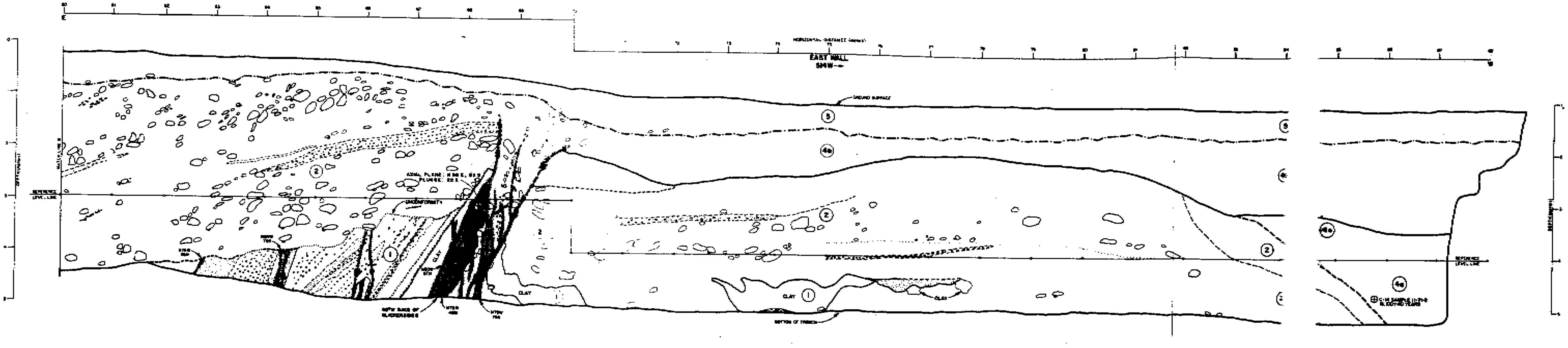


LITHOLOGIC DESCRIPTIONS
GOOSE LAKE TRENCH LOG 11–T1

Unit 5: A/B Soil Horizon
Very dark gray (10 YR 3/1 moist) silt loam; sticky; slightly plastic; loose to friable; moderate to strong ped development; very few pebbles.

Unit 4: Silt
4a:
Grayish blue sandy clayey silt; abundant organic material; upper portion of unit weathered to yellowish brown (10 YR 5.5/8 moist).
4b:
Yellowish brown (10 YR 5/8 moist) clayey silt with subrounded to well rounded pebbles and cobbles (≤ 10 cm).
4c:
Dark yellowish brown (10 YR 4/6 moist) clayey silt with trace fine sand and gravel.

Unit 3: Lake Sediments
3a: Lower Lake Sediments
Dark yellowish brown (10 YR 4/4 moist) fine sandy silt clay to clayey silt with some sand; minor rounded pea-sized gravels.
3b: Middle Lake Sediments
Strong brown (7.5 YR 5/8 moist) clayey silt with trace fine sand subrounded to well rounded pea-sized gravel; light gray (2.5 YR 7/2 moist) infillings (≤ 2 cm) of silt.
3c: Upper Lake Sediments
Yellowish brown (10 YR 5/8 moist) clayey silt with some fine sand and occasional pebbles; brownish yellow (10 YR 6/6 moist) silt infillings (≤ 4 cm width, approximately 20 cm length); trace fine sand and occasional pebbles.

Unit 2: Yager Creek Alluvium
Gravel, pebbles to boulders, 80 percent graywacke sandstone; subround to round; poorly sorted; moderately weathered to core. Local lenses of dark yellowish brown (10 YR 4/6 moist) sand, fine to coarse grained; moderate to moderately well sorted.

Unit 1: Carlotta Formation
Interbedded clay, sand and gravel
Clay: Dark gray (2.5 YR 4/0 moist) and yellowish brown (10 YR 5/4 moist) stiff clay; very plastic, very sticky.
Sand: Dark yellowish brown (10 YR 4/4 moist); fine- to medium-grained; subangular; occasional pebble layers 1 to 2 cm thick.
Gravel: Subrounded to well rounded pebble gravel, 5 cm maximum, mode 2 cm; medium- to coarse-grained sand matrix is subangular to subrounded and poorly sorted.

EXPLANATION

- Lithologic Contact; solid line where resolution is less than 2 cm, dashed line where 2–5 cm, dotted line where 5–15 cm.
- Soil Contact
- Disturbed Soil Contact
- N75W 60N — Fault; solid line where resolution is less than 2 cm, dashed line where 2–5 cm, dotted line where 5–15 cm; strike and dip of fault plane indicated; arrows indicate sense of relative movement.
- N70E 56N — Strike and Dip of jointing
- Shears

HUMBOLDT BAY POWER PLANT UNIT No. 3	GOOSE LAKE EXPLORATION LOCALITY TRENCH LOG 11–T1	13976G–6512 B-46b
Woodward-Clyde Consultants		Figure B–5b

Regarding displacement, Coppersmith reports that a scarp-derived colluvial wedge (at station 67, Figure 3) has a maximum thickness of about one meter suggesting that the single event displacement along that particular fault was about one meter. Using a different line of reasoning, he refers to the existence of the two most recent faults exposed in the trench and assumes each was produced by a separate event (noting this may not be the case). Using the net displacement (4.0 to 8.5 meters), he concludes that the displacement per event is less than or equal to 3 to 4 meters.

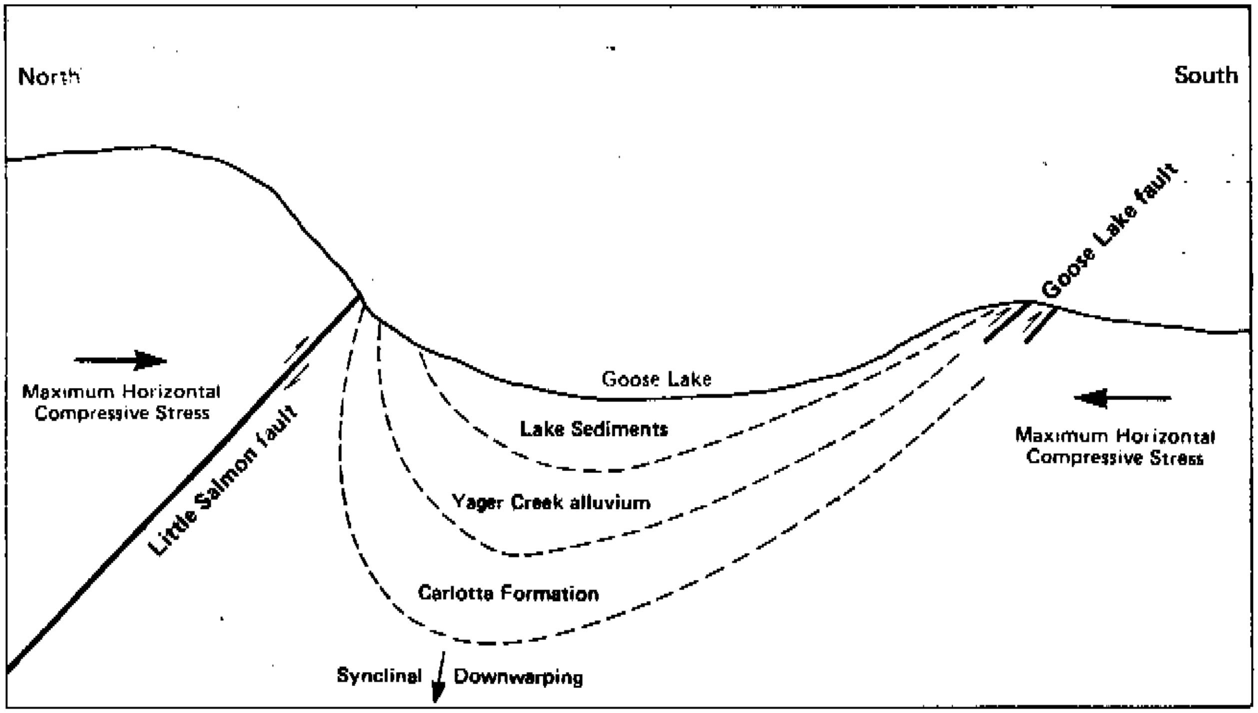
Coppersmith (p. B-21 to B-23) noted that the apparent sense of vertical movement along the Goose Lake fault is opposite that of the Little Salmon fault. In the model he presented to explain this apparent discrepancy, the regional crustal shortening occurs as both folding and reverse fault movement. He described the area between the Goose Lake and the Little Salmon faults as a syncline, and postulated that the rate of downwarping in the block exceeds the rate of vertical slip on the Goose Lake fault (see Figure 4). Stevens (p.c.) noted that Coppersmith's is not very plausible, and that it did not really account for the observed evidence supporting the strike-slip component of movement.

5. Air photo interpretation and field reconnaissance.

U.S. Geological Survey (1947, 1972) and U.S. Department of Agriculture (1954) aerial photographs of the Hydesville area were interpreted and the data plotted on Figure 5 . Two fairly well-defined zones of fault-produced features were noted: one along the Goose Lake fault, and one along fault "A." Both "faults" offset several terrace surfaces, and do not appear to offset a terrace near Fisher Road (hereafter the "Fisher Road Terrace"). Of these two zones, the Goose Lake fault appears more well-preserved, although fault "A" has been partly obscured or obliterated by recent landslide movement.

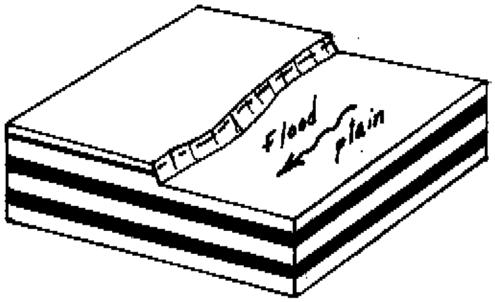
In addition to the trench data provided by Coppersmith (1980) and summarized above, the tectonic origin of the features along the Goose Lake

FER-130. Figure 4. From Coppersmith (1980).

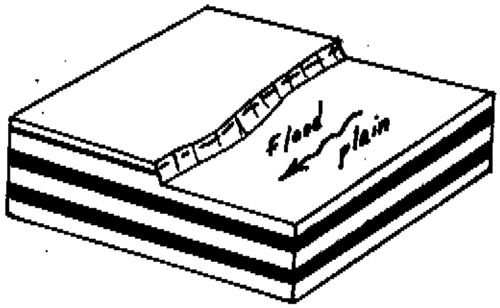


Schematic north-south cross section showing Little Salmon fault and Goose Lake fault.
Rate of synclinal downwarping is assumed to exceed rate of slip on Goose Lake fault.

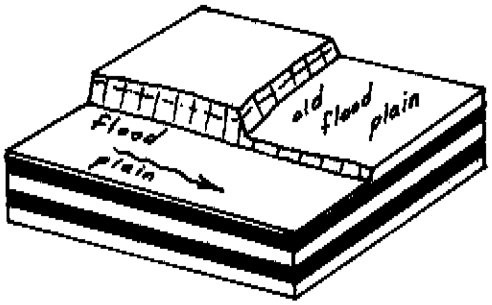
HUMBOLDT BAY POWER PLANT UNIT No. 3	SCHEMATIC NORTH-SOUTH CROSS SECTION AT GOOSE LAKE	13976G–6512 B-40
Woodward-Clyde Consultants		Figure B–6



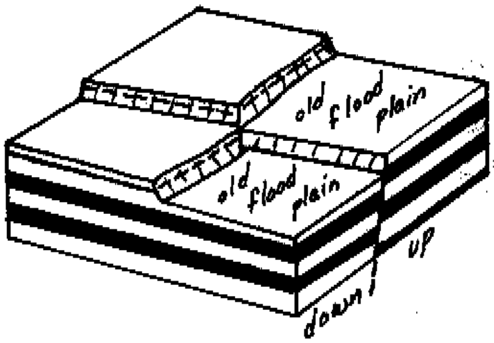
(a_1) Erosional scarp formed.



(a_2) Erosional scarp formed.



(b_1) Second erosional scarp formed.



(b_2) Second scarp formed by fault movement.

Figure 6. Hypothetical topography resulting from erosion (a_1 and b_1) and erosion with subsequent fault movement (a_2 and b_2).

fault and fault "A" can be argued on the basis of geomorphic evidence alone (schematically shown in Figure 6). If, after an erosional escarpment (such as a streambank) is formed, fault movement occurs along a fault which trends at right angles to the escarpment, both the original erosional escarpment and the fault scarp can be preserved. But, if a second erosional escarpment is formed, the first escarpment is normally partially eroded (as in Figure 6b2). Therefore, the several "crossing escarpments" present along each strongly support a tectonic origin for fault "A" and the Goose Lake fault. Also the lack of a scarp across the Fisher Road terrace (based on both air photo and field observations) strongly suggests that movement has not occurred along either the Goose Lake fault or fault "A" since the terrace surface was formed. (No evidence that the terrace surface has been highly modified was found.)

The Goose Lake fault is well-expressed, in the vicinity of Johnson Road, by a small asymetrical anticline or large "mole track" about one-half mile long (see Figure 5). Just east of Johnson Road, a linear closed depression is present on the south side of the "mole track" and the Fisher Road terrace. Between the Wolverton Gulch landslide area and the west end of the mole track, the zone is marked by a vague tonal (on the air photos) and a slight swale behind a low linear ridge (a continuation of the larger "mole track").No clear evidence of a westward continuation of the Goose Lake fault was observed, although a slight swale can be seen on the air photos in the northwest corner of section 18. As has already been noted, the Fisher Road terrace shows no evidence of fault displacement or warping. Similarly, no fault produced features are present in the present Yager Creek floodplain.

East of Yager Creek and north of Carlotta, there is a north-facing escarpment which is almost on trend with the Goose Lake fault (Figure 5 , Section 22). The orientation of this escarpment compared to that of Yager Creek, suggests that this escarpment is not erosional in origin. East of

Wilson Creek, however, this feature is not well-defined on the photos interpreted because of forest cover. Some terrace surfaces and bedding surfaces are apparent in the area between Wilson Creek and Cummings Creek; some of these surfaces appear truncated along their northeastern margins by either an unconformity or a fault (north side up based on topographic expression). Since the Little Salmon fault zone passes through this area (Ogle, 1953), these truncations are most likely an expression of movement along branches of the Little Salmon fault. An attempt was made to observe these faults along Fox Creek and Cummings Creek, but few bedrock exposures are present and no faults were observed.

Coppersmith (1980) shows fault "A" as having two branches at its western end (see Figure 2, this FER). However, no features indicative of recent fault movement were noted on the air photos along the southern branch. Coppersmith's third fault (fault "B") is depicted as "less distinct" on his Figure B-3 (p. B-11) and as an air photo lineament on his Figure B-2 (p. B-10). Some tonal lineaments, a vague curvilnear scarp, and a linear valley are present along this general trend, but may well be due to the erosional and depositional processes associated with the adjacent creek; thus fault "B" may not be a fault. As Coppersmith (Figure B-3) notes, however, the Yager Creek terraces do not appear to be well-expressed north of fault "B." Fault "B," therefore, is similar to Figure 6a of this FER: landsliding, erosion, and depostition could have obliterated the terrace escarpments north of fault "B."

6. Seismicity.

Turcotte, et al, (1980) have presented a summary of the available seismic data for the region. There is ample evidence to indicate that the Goose Lake fault lies in a seismically active region. Turcotte, et al., indicate that the major source of seismicity is the subduction zone which extends beneath the study area. They also indicate that the near surface seismic events indicate the shallow crust is also under north-south compression, but that microearthquakes are less frequent and smaller in size. They observed no correlation between surface faults and lineations and linear zones of near-surface seismicity. They do report (p. D-60, D-62) that thirty-two seismic events (magnitude not given) occurred near the northeast corner of the Hydesville quadrangle at depths of fourteen to twenty-six kilometers on April 1, 1977. A shallow event (2.36 kilometers, magnitude 2.65) also occurred in this same area (40°36.37'N, 124°00.03W) in December, 1978.

7. Conclusions.

a. Goose Lake fault.

The Goose Lake fault is very well defined to reasonably well-defined in the Hydesville area. Fairly conclusive evidence of fault movement in the last 16,100$\pm$110 years has been documented by Coppersmith (1980). While Coppersmith concludes that at least two fault rupture events have probably occurred dring the last 16,100 years, this has not been demonstrated. Repeated movemnt (not time constrained) has been demonstrated by the presence of a faulted colluvial wedge (Coppersmith, 1980), however. Additional evidence in support of fairly recent movement exists in the form of a closed depression and the well-preserved character of the "mole track" which crosses Johnson Road, as well as several faulted terrace surfaces. The most recent displacement probably occurred prior to the most recent erosional and/or depositional event which affected the Fisher Road terrace (which is probably some tens of centuries old).

Movement on the fault has apparently been oblique in nature. The fault planes exposed in the Woodward-Clyde trenches indicate that right-lateral reverse movement has occurred along a north-dipping zone of faults. The topography argues, however, for the southern block having been uplifted relative to the northern block. Coppersmith (1980) attempted to explain the features as the product of synclinal folding where the bottom of the syncline was dropping faster than the folding was taking place. This model has some serious space problems and overlooks both the strike-slip component as well as the relative position of the terrace surfaces.

The Goose Lake fault is not well-defined west of Wolverton Gulch although it may extend through that area. Just north of Carlotta (east of Yager Creek) is another north-facing escarpment and apparent offset terrace which may be an extension of this zone. Forest cover and the limited nature of the access does not permit extending the zone west of Wilson Creek.

b. Fault "A."

Fault "A" is reasonably well-defined by geomorphic features and, although no fault plane exposures have been observed, is almost certainly a fault based on geomorphic evidence (presented in section 5, above). While the feature has not been dated, it appears to offset the same terrace surfaces as the Goose Lake fault. The recency is constrained by the apparent lack of surface expression on the Fisher Road terrace. The vertical sense of movement, based on geomorphic evidence, appears to be south side up and greater amount than along the Goose Lake fault. This line of features, which is limited to the Hydesville area, strongly suggests movement has contemporaneously occurred along fault A and the Goose Lake fault and that both are likely driven by the same mechanism.

c. Fault "B."

Fault B is not a well-defined feature and has not been clearly demonstrated as being a fault or other tectonic feature. If, indeed, fault B is a fault (and not an erosional feature as indicated by arguments presented in section 5, above) then it could have moved contemporaneously with the Goose Lake fault.

9. 8. Recommendations.

Based on the information contained herin, the Goose Lake fault and fault A should both be zoned as shown on Figure 7 . While the relationship of these two faults to the regional tectonic stresses is not understood, these features are most certainly faults, are reasonably well-defined, and are probably Holocene in age (or at least are very close to being Holocene in age); thus, the criteria for zoning (see Hart, 1978) appear to have been met.

No other features addressed in this FER are recommended for zoning at this time.

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August 31, 1982

I agree with recommendations.
EWH
9/16/82